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Development of Techniques for Measurement of Left Ventricular Ejection Time

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Abstract

This study aimed to develop different measurement techniques for measurement of left ventricular ejection time (LVET) measurement from echocardiography, thoracic impedance cardiography (ICG) and peripheral photoplethysmography (PPG).

Healthy subjects volunteered for this preliminary investigation. For each subject, cardiac aortic valve movement and aortic blood flow were examined by M-mode and Doppler echocardiography simultaneously with ICG and peripheral PPG pulses for 15 s. Using all the measureable beats from each subject, the beat-by-beat measurement variability (SD of LEVT) and the mean value of LVET were compared between techniques.

The LVET measured from Doppler imaging had the smallest mean of beat-by-beat SD across all subjects (9 ms), which was better than that from M-mode echocardiography and PPG (both were 11 ms). ICG had the largest mean beat-by-beat SD (22 ms).

The mean LVET across all subjects from the M-mode echocardiography was 328 ms, which was longer than that from Doppler imaging (309 ms) ($P < 0.001$). Mean LVETs from ICG (364 ms) and PPG (348 ms) were both significantly longer those from images ($P < 0.05$).

In conclusion, with simultaneously recorded cardiac images and physiological signals, it has been quantitatively demonstrated that the ICG and PPG not only gave longer LVET measurements, but also had larger measurement variability than the M-mode and Doppler images.

1. Introduction

Left ventricular ejection time (LVET) is an important parameter to assess left ventricular performance [1]. It is usually measured noninvasively by M-mode echocardiography [2] or Doppler echocardiography [3].

It has been reported that some physiological measurements, such as impedance cardiography (ICG) and photoplethysmography (PPG), have the potential to provide easier ways to measure the LVET [4-5]. However,

limited studies have been published about the comparison between the LVETs measured from echocardiography and physiological measurements.

This study aimed to compare the LVET measurement from echocardiography, ICG and PPG on normal subjects.

2. Methods

2.1. Subjects

Healthy subjects from Newcastle Hospitals NHS Foundation Trust and Newcastle University volunteered for this preliminary investigation after obtaining consent. All the subjects were male, without any symptom or diagnosed cardiovascular disease. The age of the subjects ranged from 24 to 38 years old.

2.2. Data collection

All the measurements were performed in a quiet clinical measurement room. Aortic valve movement and aortic flow were recorded by M-mode and Doppler echocardiography from a Philips/ATL HDI 5000 ultrasound device. The impedance signal $-dZ/dt$ was recorded from an impedance cardiography TaskForce Monitor (TFM 3040i), and peripheral pulses from a PPG device.

For each subject, data were recorded for 15 s while lying still on a measurement couch with normal respiration. The sampling rate for the imaging was 200 Hz, and the physiological signals (ICG and PPG) were recorded at a sampling rate of 1 kHz.

In order to reduce the influence of uncertainty caused by physiological variation, the ultrasound, ICG and PPG devices were synchronized to allow the images and physiological signals to be recorded simultaneously. A common lead I ECG with a preceding blank zero line was recorded by all the devices to provide a time reference. These measurement devices were switched on and off in a sequence, as shown in Figure 1, to ensure that the same 15 s recordings were obtained for analysis from all the devices.

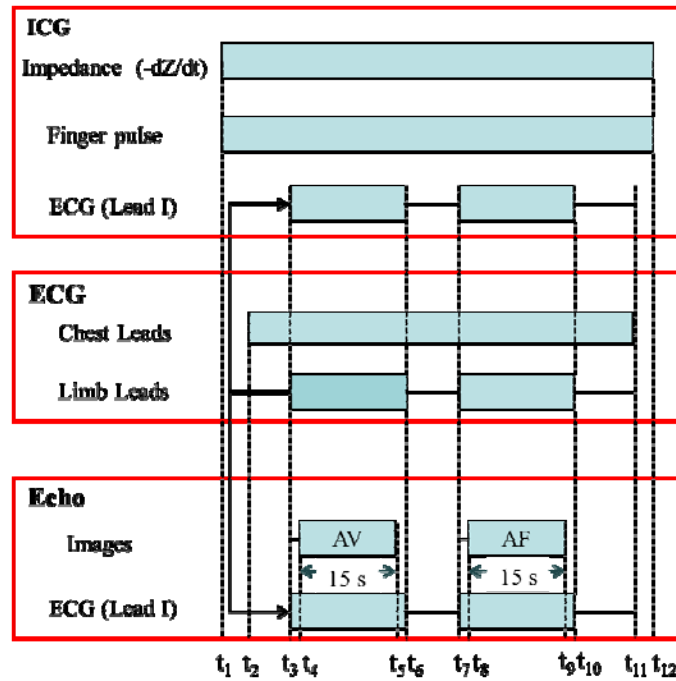


Figure 1. Timing sequence of switching devices on ($t_1, t_2, t_3, t_4, t_7, t_8$) and off ($t_5, t_6, t_9, t_{10}, t_{11}, t_{12}$) for simultaneous recording.

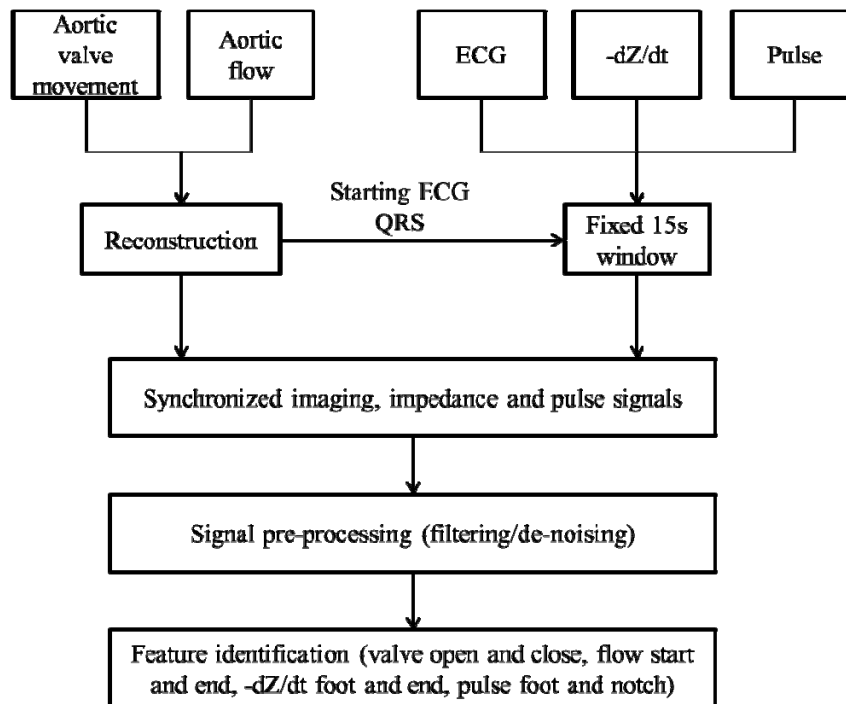


Figure 2. Procedure for signal synchronization, pre-processing and feature identification.

2.3. Signal synchronization and pre-processing

Signals from the separate devices were downloaded to an analysis computer and synchronized with the markers recorded on the ECG. The flowchart of signal synchronization, pre-processing and feature identification is shown in Figure 2. The position of the ECG QRS complex immediately before the first frame of the images was used as the common start, after which a 15 s window was used to extract the simultaneously recorded signals.

The M-mode and Doppler images were saved frame-by-frame in DICOM format. An algorithm was developed to extract the images from each frame to reconstruct pixel series. An example of the reconstructed imaging pixel series with the simultaneous physiological signals over 15 s is shown in Figure 3.

2.4. LVET measurement

LVET was obtained beat-by-beat from the 15 s recordings on images, impedance and pulse (Figure 4):

- aortic valve movement: from the valve opening to closing;
- aortic flow: from the flow start to the end;
- $-dZ/dt$: from the systolic foot to the end;
- pulse: from the foot to the notch.

2.5. Data and statistical analysis

For each subject, the average LVET and measurement variability (SD of beat-to-beat LVET) were calculated from the measurements on all the beats within the 15 s. The measurement variability of each technique was then

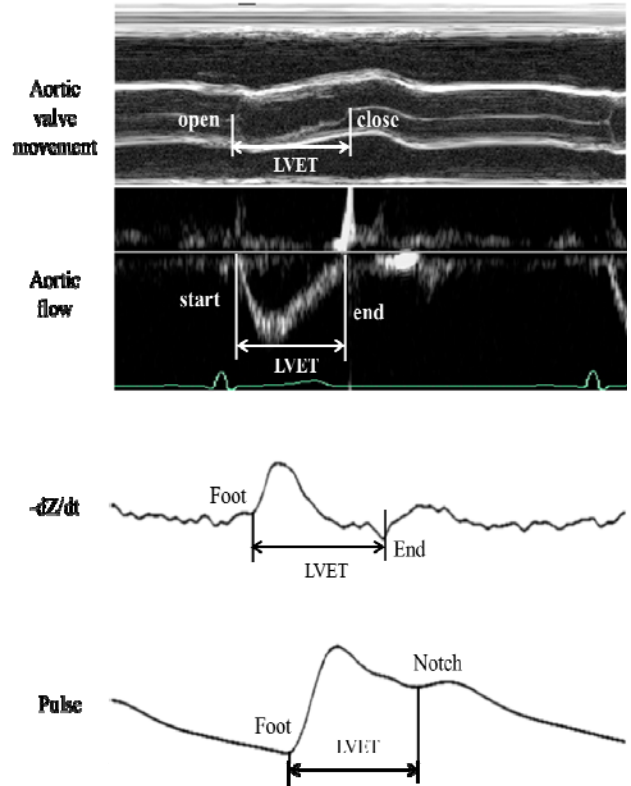


Figure 4. Example of LVET measurement from echocardiogram aortic valve movement, aortic flow, derivative impedance and finger pulse.

examined by the average SD across all subjects.

Based on the average LVET from each individual, the multiple-comparison was employed to assess statistical differences of LVET measurement between techniques.

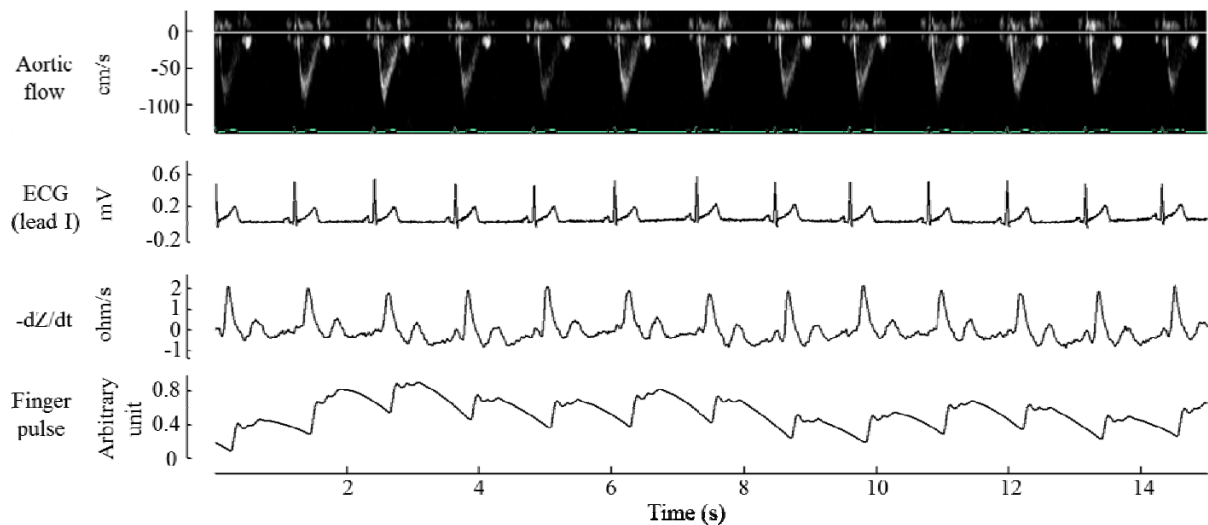


Figure 3. An example of the reconstructed Doppler image for aortic flow with simultaneous physiological signals.

3. Results

3.1. Measurement variability

Five subjects were studied. The LVET measurement variabilities across the 15 s recording are given in Table 1. Doppler imaging for the aortic flow provided the smallest mean SD across all subjects (9 ms), while ICG gave the largest mean SD (22 ms). M-mode echocardiography and PPG had the same mean SD (11 ms).

Table 1. Beat-by-beat variability (SD: ms) of LVET on each subject measured with different techniques.

Subject	Aortic valve	Aortic flow	-dZ/dt	Pulse
1	18	8	23	15
2	12	8	17	11
3	13	9	23	13
4	6	12	15	12
5	7	6	34	6
Average	11	9	22	11

3.2. Comparison of LVET measurement from different techniques

The overall mean LVET across all subjects from the M-mode echocardiography for the aortic valve movement was 328 ms, which was longer than that from the Doppler imaging for the aortic flow (309 ms), but significantly shorter than that from ICG (364 ms) and PPG (348 ms) (all $P < 0.05$).

4. Discussion and conclusion

This study quantitatively compared the LVET measurement based on the simultaneously recorded echocardiograms, thoracic impedance and peripheral pulse. Our results demonstrated that LVET measurement variability from impedance and pulse tended to be larger than that from echocardiography. ICG gave the largest variability among these four techniques, which is probably because other factors, including blood volume changes in the lungs, aorta, ventricles and central great vessels would also influence the thoracic impedance and thus change the impedance features [6].

LVET measured from ICG and PPG were significantly longer than that from images. This might be because the thoracic impedance and peripheral pulse are also influenced by vascular function in addition to the cardiac ventricular ejection.

In conclusion, although physiological measurements of ICG and PPG have the potential to provide cardiac function data, they do not yet have the accuracy needed.

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